Selective Formation of InAs Single and Multiple Quantum Dots on GaAs Wire Structures for Application of Single Electron Memory

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We have been reporting on the formation of position and number controlled self-assembling InAs quantum dots (QDs) on the top of GaAs wire structures formed by selective area metalorganic vapor phase epitaxy (SA-MOVPE). In this paper, we will describe the formation mechanism of InAs QDs during SA-MOVPE and its dependence on the direction of wires. In particular, step-induced islanding is utilized to form a *single* InAs QD at the bend of the wires.

Experimental procedure is as follows. Firstly, GaAs wire structures were selectively grown on (001) GaAs substrates partially covered with SiON mask at 700°C. The mask pattern had periodic wire openings either along the [$\bar{1}$10], [110], or [010] direction. The width of the openings W was ranging form 20μm to 0.5μm. Next, InAs was grown on the top of trapezoidal GaAs wires at 480 $\sim$ 500°C. The nominal amount $t_{\rm InAs}$ of InAs supply was also varied from 2ML to 4ML. The main results are listed below.

(1) The cross section of GaAs wire is either mesa or triangular ridge structures consisting of facet sidewalls and top (001) surface, which depends on the amount of growth, the width and direction of wire opening. It is noted that the top (001) are not atomically flat in all structures. For example, for the mesa structures along [$\bar{1}$10] and [010], formation of high-index facets and enhancement of the growth (ridge growth) were clearly observed on the top (001) surface near the {111}A and {110} facet sidewalls, respectively. Such ridge growth is most prominent in the mesas along [010] and less along [110]. This suggests the difference of step density on the top in three mesa directions. On the other hands, ridge structures which are formed for narrower opening width patterns have rounded top shapes.

(2) Figure 1 shows typical SEM images of InAs QDs formed on GaAs mesa structures, and histogram of QD position measured from the center of the mesa. Here, W = 10μm, and the amount of GaAs and InAs supply corresponds to 400nm and 3ML, respectively. It is clear that the dot distribution depends on the direction of wires. In particular, the dot density is the largest at the mesa edges for wires along the [$\bar{1}$10] and [010] directions, where the step density is expected to be large as a result of ridge growth. The QD distribution on mesas along the [110] is more or less uniform except for the depletion region near the edges. Furthermore, in the mesas along [010] (Fig. 1(c)), large QDs are formed, and the density is about half of the other two directions. We attribute to these results to the difference of In migration between top surface and sidewall facets[1], and to the step-induced islanding at the mesa edge.

(3) Figure 2 shows SEM images of GaAs ridge structures after the growth of 2ML-thick InAs for W = 0.8μm. No QDs were formed for ridges along [$\bar{1}$10] and [110], which presumably because of too small InAs supply for QD formation in contrast to our previous results[2]. On the other hand, large dots or disk-like structures were formed on ridges along [010]. These results also suggests the difference of formation process of QDs in wires in three directions.

(4) In order to control the number of QDs, we prepared a mask pattern of Fig. 3(a) and grew GaAs and InAs ($t_{\rm InAs} = 2ML$). An SEM image after growth is shown in Fig. 3(b). We can clearly see a single InAs QD is formed at the each bend of ridge structures directed towards the [110] and [010]. This position and number controlled QDs is realized by utilizing the difference of formation process between two wire directions and step-induced islanding of InAs.

The present scheme for the formation of position and number controlled QDs on GaAs wire structures are very promising for device application. Possibility of the memory operation with a GaAs ridge quantum wire and a single InAs QD will also be discussed.

References

[1] C. K. Hahn *et al.*, to be published in J. Crystal Growth (2000).
[2] Y. Arituka*et al.*, Mat. Res. Soc. Symp. Proc. **570** (1999) 97.

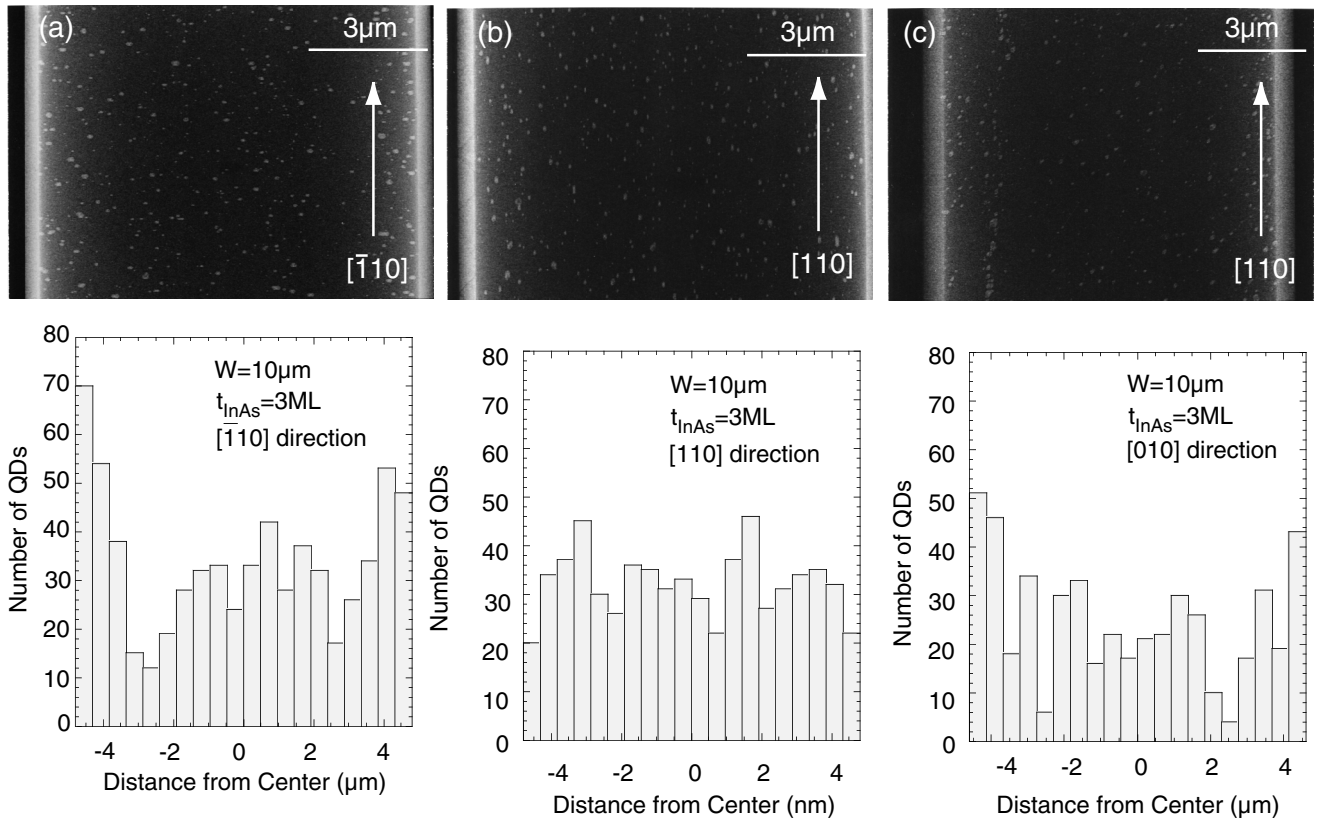

Fig. 1 SEM images of InAs QDs formed on GaAs mesa structures and their historgram of distribution from the center of the mesa. The direction of mesas are, (a) [$\bar{1}$10], (b) [110], and (c) [010].

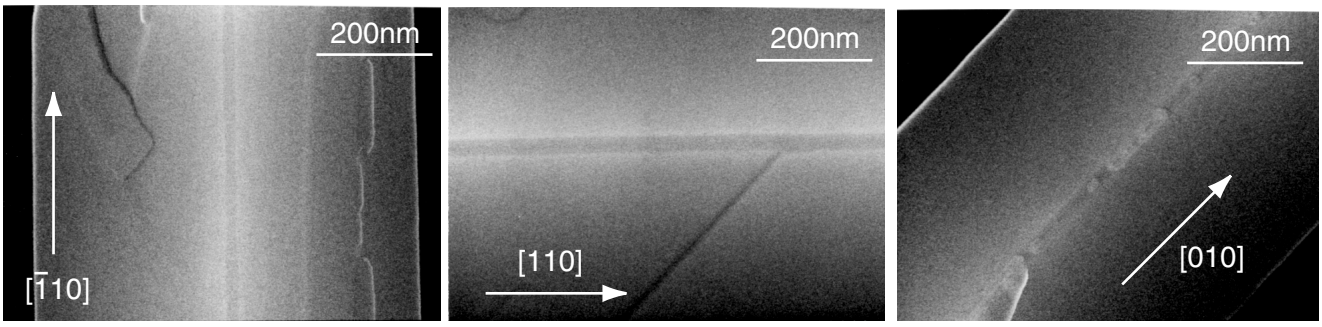

Fig. 2 SEM images of ridge structures after the growth of InAs (t_{InAs}=2ML). The direction of mesas are, (a) [$\bar{1}$10], (b) [110], and (c) [010].

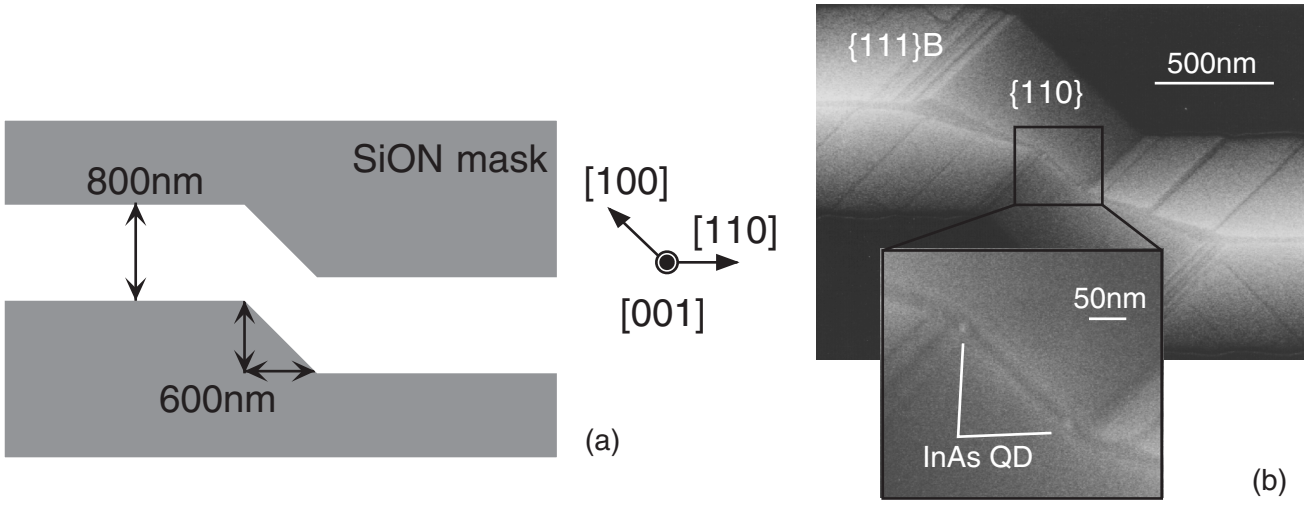

Fig. 3 (a) Schmatic illustration of the mask pattern. (b) SEM image of single InAs QD formed at the bend of GaAs wire structures. The size of QD is 20nm.